Tunable, Solid State Laser for HF Mirror Metrology

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ABSTRACT

HF mirror metrology is currently costly and time consuming, requiring laser component delivery to an HF laser site, and operation of another HF laser to reach relevant wavelengths. Coherent Technologies, Inc (CTI) has developed a solid state Cr:ZnSe laser pumped by a Tm:YALO laser that provides up to 1.1W of output power with 1.1nm linewidth at 2.64μm, an HF laser line. The laser can also tune to other HF laser lines in the wavelength range of 2.64μm to 2.8μm. The Cr:ZnSe laser was used to measure the reflectivity of HF mirror samples provided by TRW. Examples of other possible applications of this source include beam train alignment and preliminary testing of diagnostic subsystems that measure HF laser output power, wavefronts, and beam profiles. Such a direct laser source is simple and can potentially achieve high intensity stability, allowing for a robust and compact HF laser surrogate. Moreover, power scaling is straightforward.
Keywords: Tunable; infrared; Cr:ZnSe lasers; HF lasers; metrology

1. Cr^{2+} DOPED CHALCOGENIDE LASERS

Three significant advantages of Cr:ZnSe are that (1) the material has an extremely broad absorption band (allows it to be pumped by a variety of sources), (2) the laser has an extremely large emission cross-section (high gain) and (3) the laser material has a near-unity fluorescence quantum efficiency at room temperature (high temperature operation possible). An absorption curve is shown in Figure 1. It is apparent that pump sources in the 1.5 μm to 2.0 μm wavelength region can be used to excite the Cr^{2+} ion in the ZnSe host. CTI has demonstrated CW operation of Cr:ZnSe lasers using a NaCl:OH^- color center laser operating at 1.58μm, a 1.8μm diode laser, and a Tm:YALO laser operating at 1.94μm as pump sources. For most laser geometries, the optimal pump wavelength is expected to be around 1.8 μm. However, the broad absorption band provides a means of varying the heat load per unit length in the laser crystal without varying the active ion concentration (i.e. provides another design "knob" to tweak).

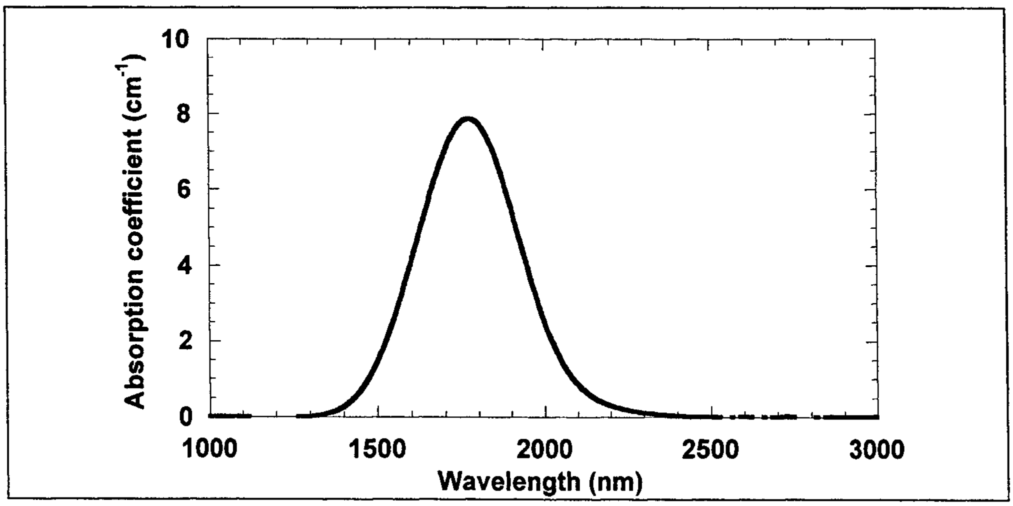

Figure 1. The Cr^{2+}:ZnSe absorption spectrum. The sample was prepared by diffusion doping. It is apparent that any pump wavelength in the 1.5 to 2.0 μm range is suitable.

The Cr^{2+} ion has essentially two electronic states since transitions to higher levels (which coincide with the material's bandgap) are spin-forbidden and, presumably, very weak. In this respect the laser is similar to the Ti:sapphire laser that

has proven to be highly commercially successful. An advantage is the expected absence of loss mechanisms, such as upconversion and excited-state-absorption, that plague many other SWIR and MWIR laser materials.
Some advantages of the Cr:ZnSe laser system are listed below.

- Broad tunability (lasing from 2.1-3.1μm demonstrated)
- Broad absorption bands (relaxed pump wavelength constraints)
- Ability to directly diode pump using strained-layer InGaAsP/InP diode lasers (demonstrated by multiple groups)
- Large gain cross section ($\sigma_{emis} \sim 9 \times 10^{-19}$ cm^2)
- Minimal problem of excited state absorption (no spin-allowed excited state transitions from the upper laser level)
- Near unity fluorescence quantum efficiency at 300 K (enables efficient room temperature operation)
- Can produce material by several techniques (diffusion doping and modified Bridgman growth)
- High thermal conductivity – better than YAG (18 W/m•K in ZnSe versus 13 W/m•K in YAG).[1]
- High IR (0.6-20 μm) transparency
- Readily available host material (polycrystalline window material works fine)

The main disadvantage of Cr:ZnSe is a higher temperature dependence of refractive index ($\delta n/\delta T$) than other solid-state laser materials, such as YAG. A high $\delta n/\delta T$ (61×10^{-6} at 300 K in ZnSe compared to 7.3×10^{-6} in YAG) means that thermal lensing will be more of a concern in high power ZnSe lasers than in YAG lasers. This problem can be addressed by appropriate laser design (for instance disk, slab, and waveguide designs where thermal lensing is inherently mitigated).

2. Cr:ZnSe LASER TEST RESULTS

CTI has conducted work with Cr:ZnSe lasers concentrating on CW operation, modelocking, and power scaling.[2] To meet HF laser surrogate requirements, however, CTI concentrated on line narrowing and tuning of a Watt-level Cr:ZnSe laser. The following points summarize achievements to date on this program:

- Constructed a 6W continuous wave (CW) and 3W average power Q-Switched Tm:YALO laser
- Constructed a tunable Cr:ZnSe laser that tunes 0.75 microns Q-Switched and 0.63 microns CW
- Measured emission spectra of the materials Cr:ZnSe, Cr:CdSe, and Cr:Cd_xZn_{1-x}Te, and concluded that Cr:ZnSe was the best thermal candidate and Cr:CdSe may be the best spectral candidate for possible future work

Each of these highlights are described in more detail below.

The laser resonator design for the Tm:YALO laser is shown schematically in Figure 2.

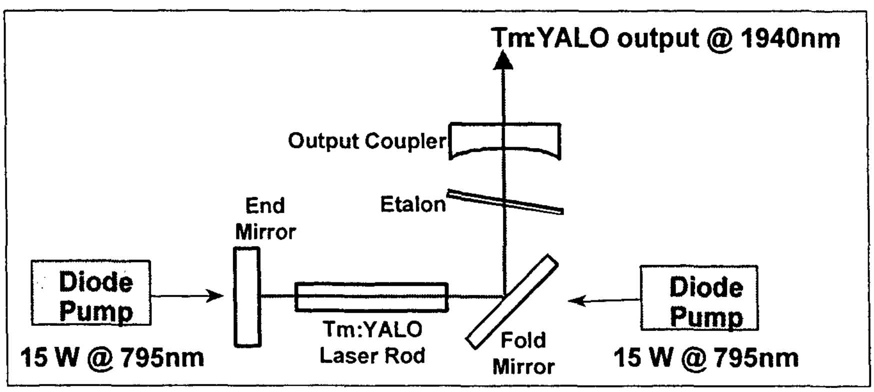

Figure 2: Plan view of the Tm:YALO laser used in the Phase I program's laboratory demonstration.

Since the 3-level Tm:YALO laser increases in efficiency with cooling, the laser head mount incorporates 4 thermo-electric coolers (TEC's). For this work, the laser was run at room temperature and produced sufficient performance for reflectivity survey demonstrations. A copper rod mount is thermally contacted via indium foil to the Tm:YALO rod. A 45 degree incidence dichroic mirror placed in front of the rod reflects the 1940nm Tm:YALO light but passes the 795nm diode pumping light, allowing diode laser end-pumping into the Tm:YALO rod. The Tm:YALO laser can provide up to 6W of power, of which 5W is incident upon the Cr:ZnSe laser after passing through an optical isolator.

The CW Cr:ZnSe laser resonator is shown in Figure 3. It is a folded linear resonator with a waist midway between the two curved mirrors to counteract thermal lensing in the pumped Cr:ZnSe rod. A Brewster plate, prism and two etalons have been used to successfully line narrow and tune the laser. The etalons are 150 and 300 microns thick, and are uncoated fused silica.

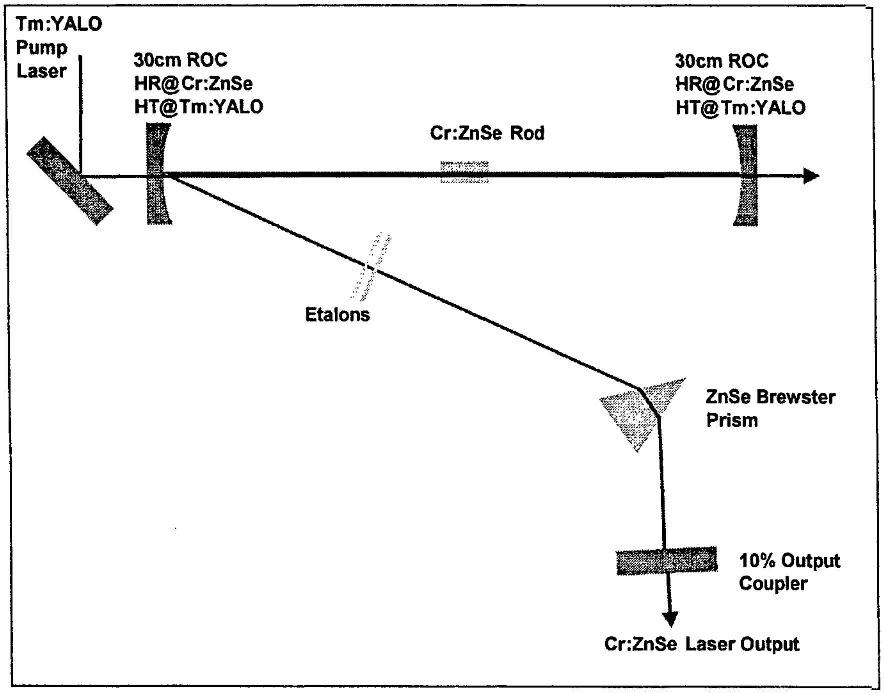

Figure 3: Resonator schematic of the Cr:ZnSe tunable laser, which produced up to 1.4W output power at 2500nm.

The Cr:ZnSe laser rod was 6mm long and absorbed 3W of the 5W maximum pump power incident on the rod. The output power vs wavelength at 5W Tm:YALO pump power is shown in the plot below, Figure 4. The laser had over 600nm continuous-wave tuning range and over 1W output power at the peak of the tuning curve.

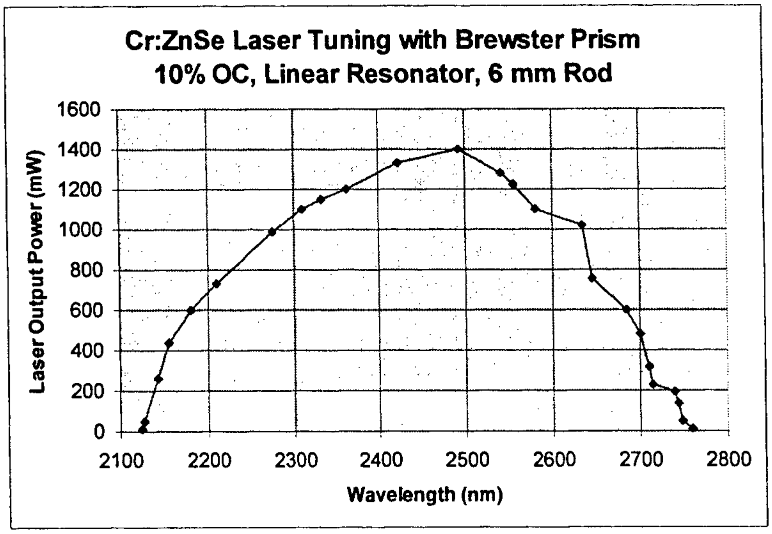

Figure 4: Plot of the output power versus wavelength for the CW Cr:ZnSe laser.

The spectral width of the laser with two etalons and a Brewster prism tuned to one of the HF 1-0 band lines, 2640nm, was measured. The full width half maximum is 1.1nm. The power output at this wavelength is 1.09W. The wavelength tuning range extending only to 2760nm, which is a shorter wavelength than reported by others; for example, CW Cr:ZnSe lasers have been tuned from 2000-3100nm, with appropriate laser design.[3] It is therefore possible that longer wavlength tuning is currently limited by cavity optics, crystal coatings, or atmospheric absorption.
CTI has found that the emission spectrum of pumped Cr:ZnSe shows a significant increase in power when the long path of the monochromator is purged with dry nitrogen in the 2600 to 2900nm range. The original detector was replaced with a PbSe detector, which has a flatter spectral response that extends further into the infrared.

The purged and unpurged emission spectrum of the Cr:ZnSe rod which is pumped by Tm:YALO is shown below in Figure 5. The emission spectrum was taken using a PbSe detector, which has a known flat response throughout the 2 to 4 micron wavelength range. This measurement confirmed that the emission is severely affected by atmospheric absorption in the wavelength region of 2.6 to 2.9 microns.

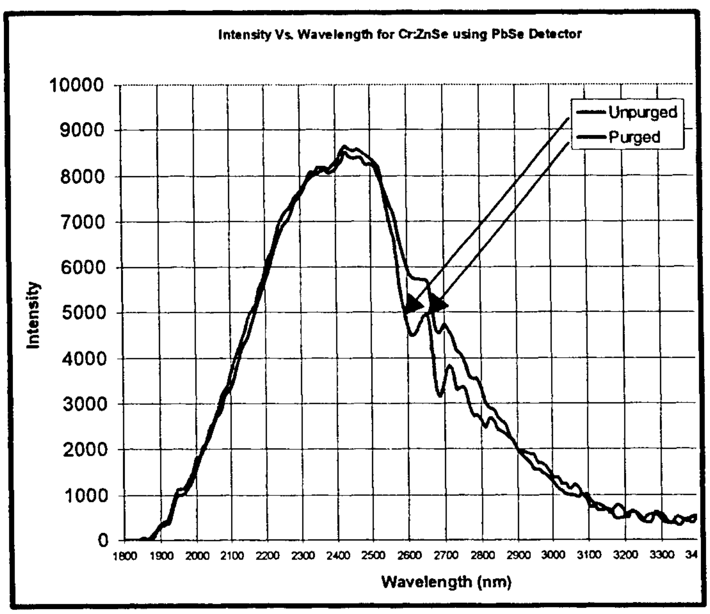

Figure 5 The emission spectrum of Cr:ZnSe with a flat response PbSe detector. Lasing in the 2.6 to 2.8 micron region would be particularly affected by atmospheric absorption lines.

Note that the purging for these emission spectra were not complete and that the path from the pumped crystal to the monochromator (the interior of which is purged with dry nitrogen) remains exposed to air and any residual atmospheric absorption. Therefore this result should be viewed as qualitative.

To investigate pump threshold effects on laser tuning, CTI measured the tuning range of a gain-switched Cr:ZnSe laser, using a 1kHz repetition rate, 3W average power Q-Switched Tm:YALO laser as the pump source. Given the much higher intensities of the Tm:YALO laser, the gain-switched Cr:ZnSe laser was expected to operate much further above threshold, yielding a tuning range that extends further into the infrared. The CW and gain-switched Cr:ZnSe lasers had very similar tuning ranges, indicating that our tuning limitation is probably related to a "non-gain" cause such as optical coatings or atmospheric absorption – both of which can be improved. The cavity used for the measurement is shown in Figure 6.

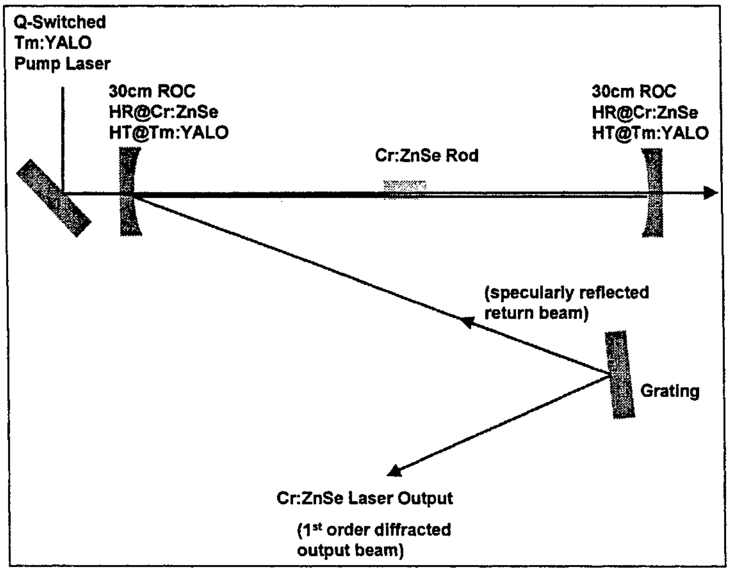

Figure 6: Layout schematic of the grating tuned Cr:ZnSe laser, pumped by a Q-Switched Tm:YALO laser.

The gain-switched laser, which was grating-tuned in the first order Littrow configuration, produced a tuning range of 750nm, which is the largest tuning range demonstrated at CTI. The resonator was tuned by rotating the grating, which changed the wavelength that was diffracted back into the resonator as feedback. The system tuned from 2050nm to 2800nm, and showed an output power that was strongly dependent on the grating diffraction efficiency with wavelength. This result is significant because it showed that the laser can indeed tune further into the infrared, but may still be limited by atmospheric absorption and optical coatings.

The Q-Switched Tm:YALO pump laser increased the gain remarkably, and it is interesting to note that the tuning range in the short range extended well into the region where Cr:ZnSe is absorbant – note that others have used the wavelength of 2013nm to PUMP a Cr:ZnSe laser[4]. Therefore, it is expected that with improvements beyond the scope of the current work, such as a higher power pump laser, improved optical coatings, and reduced cavity loss due to background atmospheric absorption, the tuning range of the CW output format Cr:ZnSe laser can be extended.

3. HF AXICON CONE MIRROR REFLECTIVITY SURVEY RESULTS

HF laser mirrors for metrology experiments were supplied by TRW. Specifically, an aluminum substrate waxicon cone coated with ThF_4 and ZnSe was used, which is a typical mirror shape for an unstable HF laser resonator. CTI has conducted a reflectivity survey of the cone at 2640nm wavelength for comparison to previous TRW measurements, which used a white light source. 2640nm was chosen as it is the wavelength of the P1(4) HF laser line, and the Cr:ZnSe laser could tune to it and provide over 1W output power. The setup used to measure the reflectivity is shown in Figure 8.

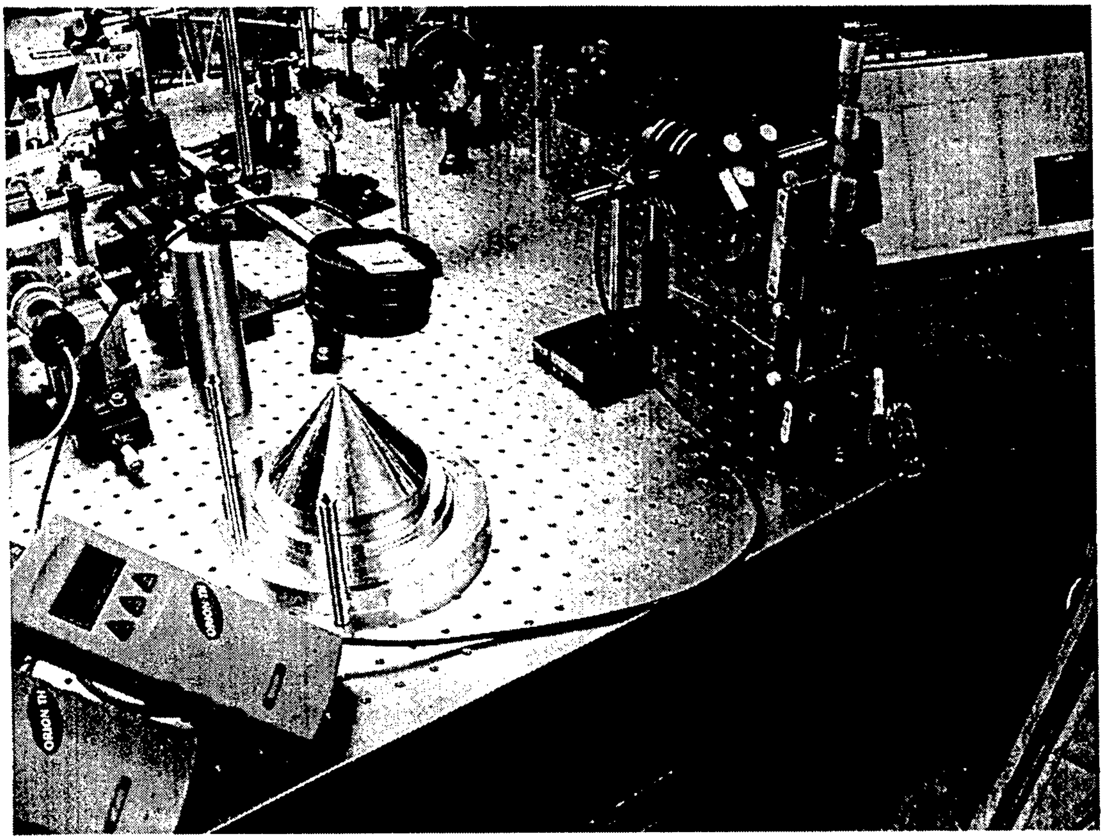

Figure 8: Setup to measure the reflectivity at 2640nm of the HF mirror cone. Two mirrors act as a vertically translatable periscope to send the beam at scanned heights onto the cone. The cone is marked and rotated within locating pins after each vertical scan.

Throughout the axicon cone survey the laser produced 1092mW±2.5% intensity at 2640nm over the four hour scan. After each reflectivity measurement the incident intensity was measured. The two detectors for incident and reflected intensity were cross-checked for response. The transmission of the laser from the incident intensity detector past the two periscope mirrors was found to be 93.7%, which was used to correct the data.

Figure 9 shows CTI's measurement in the plot format equivalent to that done in the past, except at the HF laser wavelength 2640nm. Only the average reflectivity of the cone as a function of height above the base is shown. The cone was visibly damaged, showing flaking and patchy discoloration, so it was expected that the reflection would not be 100%. No trend in reflectivity is seen with height, but that was not expected given that the measurements were done on the lower 50mm height of the cone, where the reflectivity remained fairly constant in the white-light scan. It was difficult to measure the reflectivity nearer the tip due to the severe curvature of the cone – the tip had a radius of curvature of ~0.5cm.

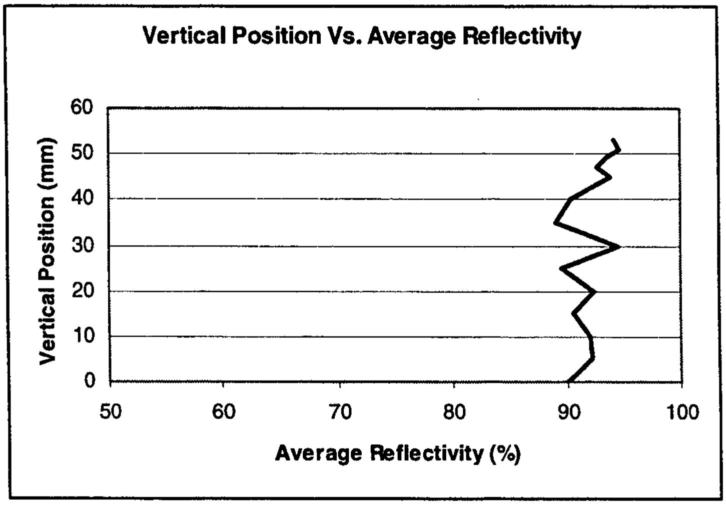

Figure 9: Plot of the average reflectivity around the cone with height.

The reflectivity of the cone as a function of both azimuthal angle and height above the cone base is shown below in Figure 10. The local drops in reflectivity could be quite severe, going to 50% in localized areas, which appeared to visibly correlate to the flaking parts of the cone.

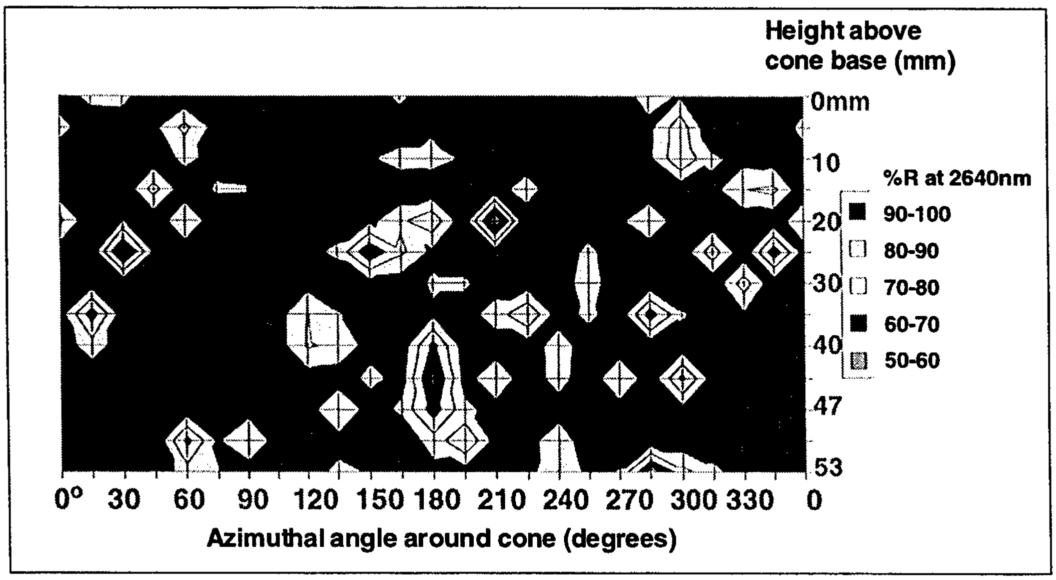

Figure 10: Plot of the measured reflectivity in percent with azimuthal angle and height in mm above the base of the HF mirror cone.

These measurements showed that mirror metrology with extensive spectral and spatial resolution could be conducted with the current Cr:ZnSe laser.

Several attempts were made to detect absorption in the HF mirrors with a focussed Cr:ZnSe laser beam and a coincident green HeNe laser beam. Despite scanning the visible laser beam repeatedly over the area illuminated by the Cr:ZnSe laser, and looking for deflection at a distance calculated to be more than sufficient to see deflection movement, no absorption by deflection was observed.

4. CONCLUSIONS

In conclusion, the results of the Cr:ZnSe laser reflectivity mapping show that the laser is sufficient to conduct spectrally and spatially accurate mirror metrology surveys. As a solid-state laser source it can significantly reduce the cost and time needed to verify a newly-developed mirror's optical properties, accelerating HF laser development. Moreover, for maintenance, beam alignment and diagnostic checking, the laser can be built on a smaller or larger scale, and be used to streamline HF laser operation and preparation procedures. In short, a Cr^{2+} chalcogenide laser is well matched to multiple HF laser surrogate requirements.

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